

# HEARING in birds, lizards and mammals

Comparative Neurobiology 3320

ANIM3320

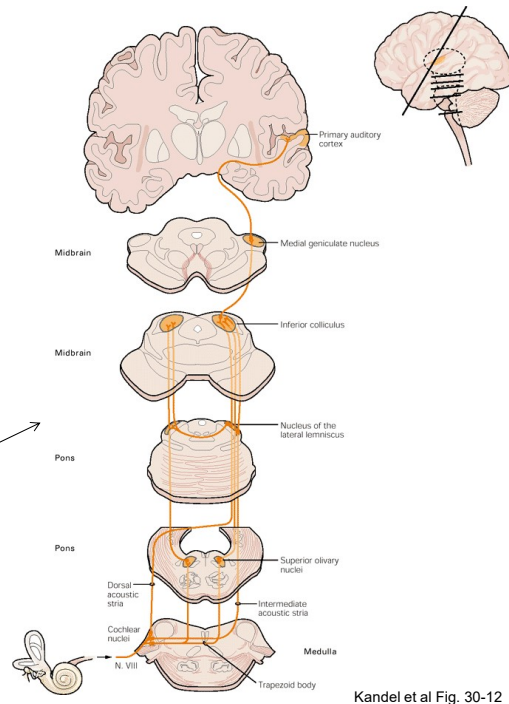
Helmy Mulders 2019

## Lecture outcomes

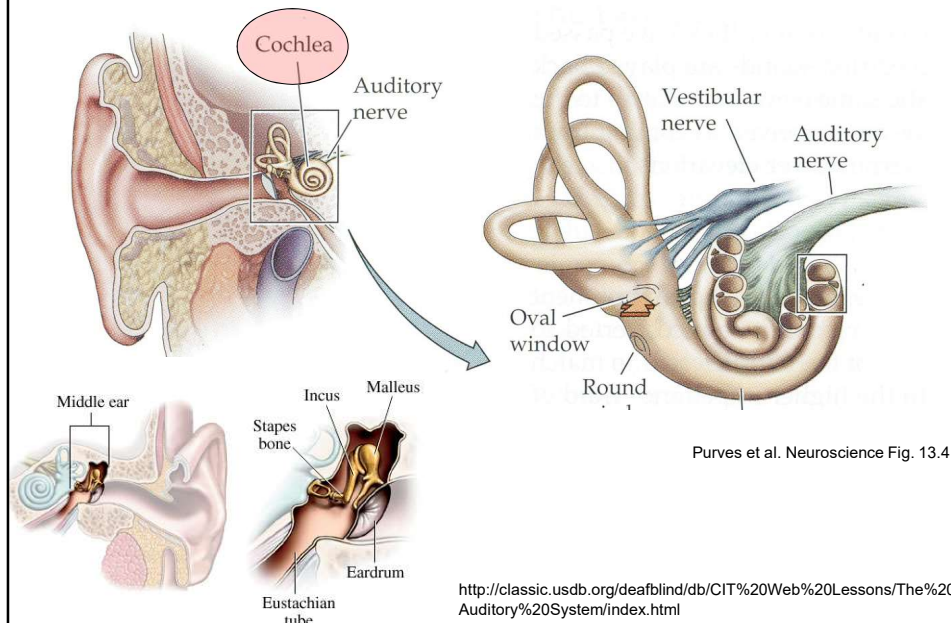
- Explain differences between species (mammals, birds, lizards) with regard to:
  - sensory epithelium
  - hair cell anatomy
  - ratio of ganglion cells vs hair cells
- Describe some of the known relationships between anatomy and function in the auditory system

## Basic anatomy and physiology of hearing

### Human ascending auditory pathway



## The external, middle and inner ear



## The inner ear: the mammalian cochlea

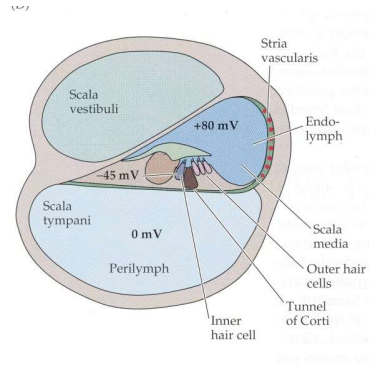
Greek κοχλίας : 'snail'

Three Fluid filled compartments

- *scala vestibuli (SV), tympani (ST) and media (SM)*

Two different fluids

- perilymph (~blood plasma) SV, ST
- endolymph (high  $K^+$ , low  $Na^+$ ) SM

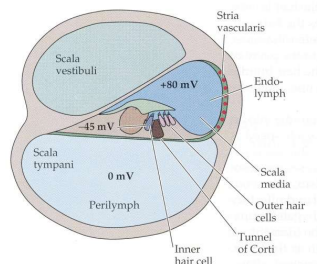
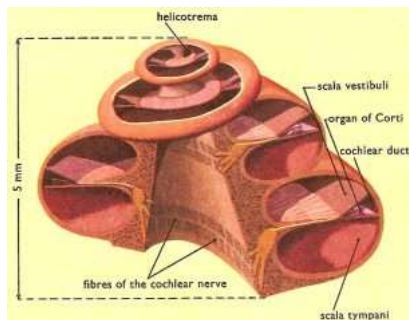


Purves et al. Neuroscience Fig. 13.8

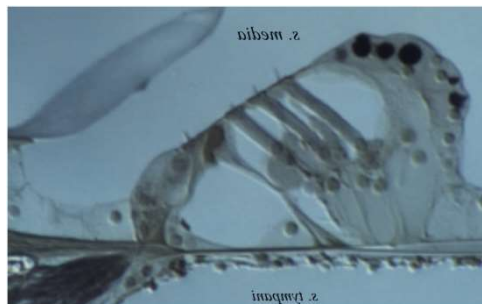
[http://www.daviddarling.info/encyclopedia/O/organ\\_of\\_Corti.html](http://www.daviddarling.info/encyclopedia/O/organ_of_Corti.html)

## The Inner Ear

Organ of Corti:  
Mammalian sensory epithelium  
named after **Alfonso Corti**  
(1851).



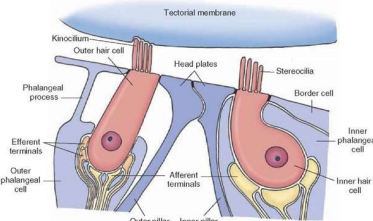
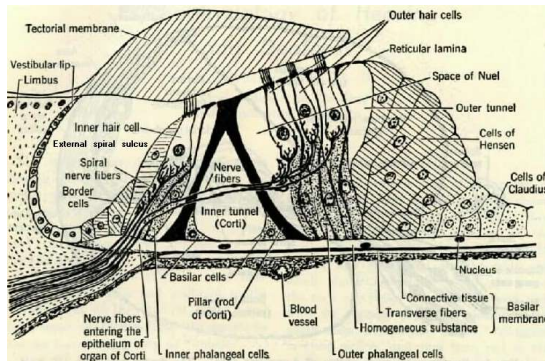
Purves et al. Neuroscience Fig. 13.8



M. Lenoir (unknown scale)

## Organ of Corti

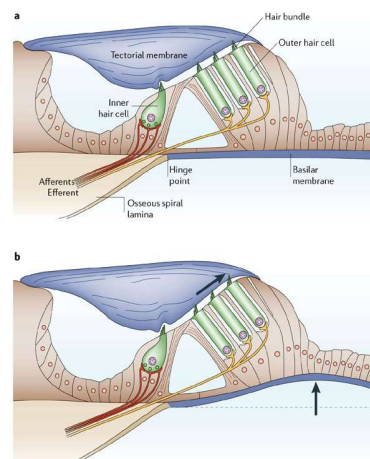
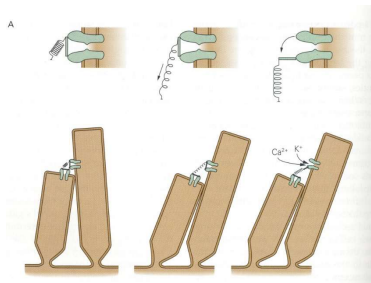
**Organ of Corti** contains specialized cells along the length of basilar membrane (which moves in response to sound-waves). Inner and outer hair cells have stereocilia that when move, open and close ion channels allowing depolarization and hyperpolarization: Mechano transducers



<http://hearinghealthmatters.org/hearinginternational/2014/cochlear-explorers-part-iii/> <http://what-when-how.com/neuroscience/auditory-and-vestibular-systems-sensory-system-part-1/>

## Mechano transduction

Stereocilia/hair bundles are bent by basilar membrane vibration causing shearing movement relative to tectorial membrane



Kandel, Schwartz and Jessell. Principles of neural science. 4<sup>th</sup> ed. Fig. 31.3

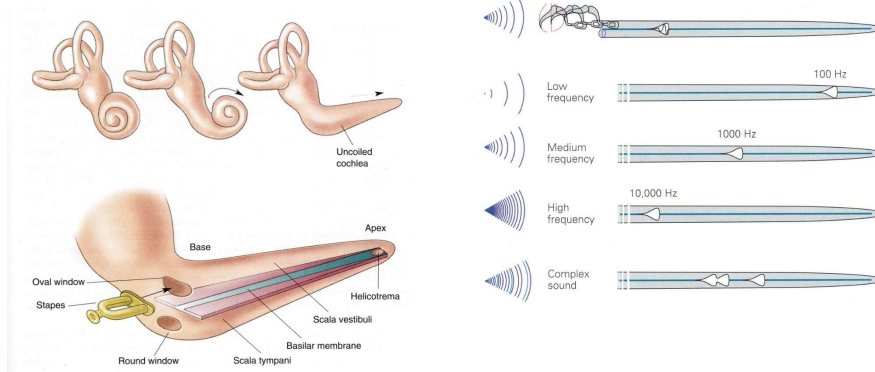
**Figure 2** Cellular structure of the sound-detecting organ of Corti.  
Fettiplace R and Hackney CM (2006) The sensory and motor roles of auditory hair cells  
*Nat. Rev. Neuro.* 7: 19–29 doi:10.1038/nrn1828

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## Basilar membrane motion: Tonotopic organization

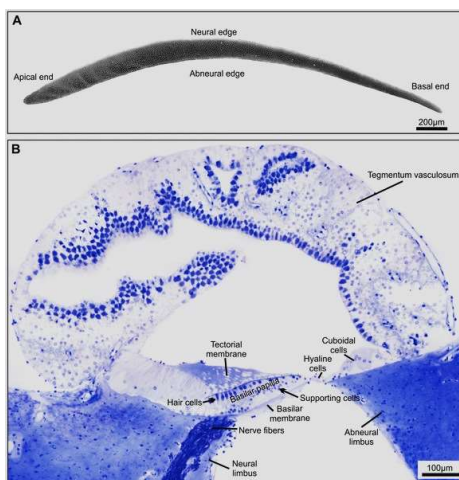
### Uncoiling the cochlea



<http://classic.usdb.org/deafblind/db/CIT%20Web%20Lessons/The%20Auditory%20System/index.html>

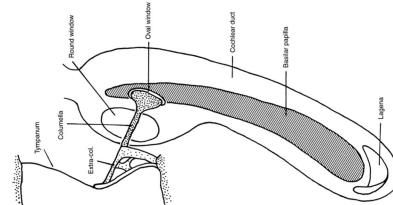
Kandel, Schwartz and Jessell Principles of neural science Fig. 30.3

## The sensory epithelium in birds



Basilar papilla: equivalent to organ of Corti

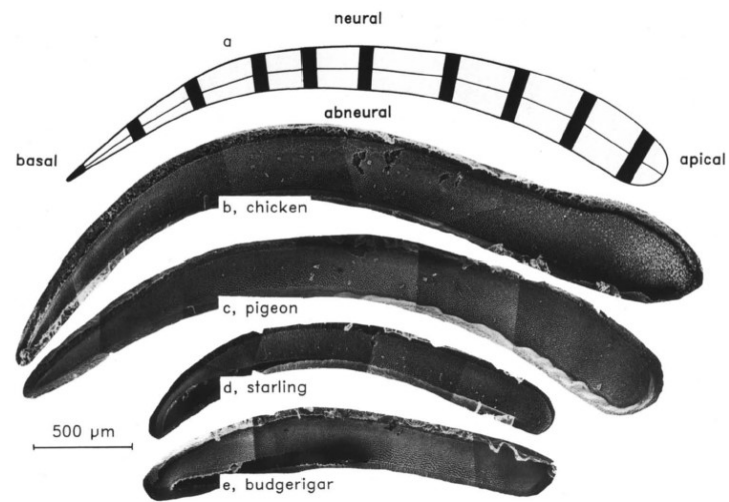
Not spiral shaped



Necker (2000)

Corfield et al., (2011) PLoS ONE 6.,

## Basilar papilla in birds

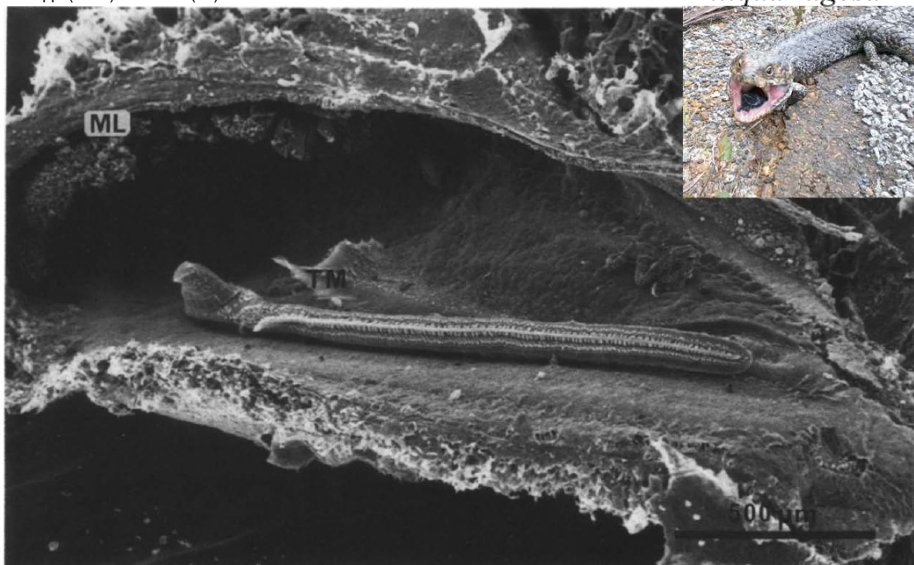


Gleich & Manley (1988) Hear Res.

## The sensory epithelium in Lizards

Koppl (1988) Hear Res (35).

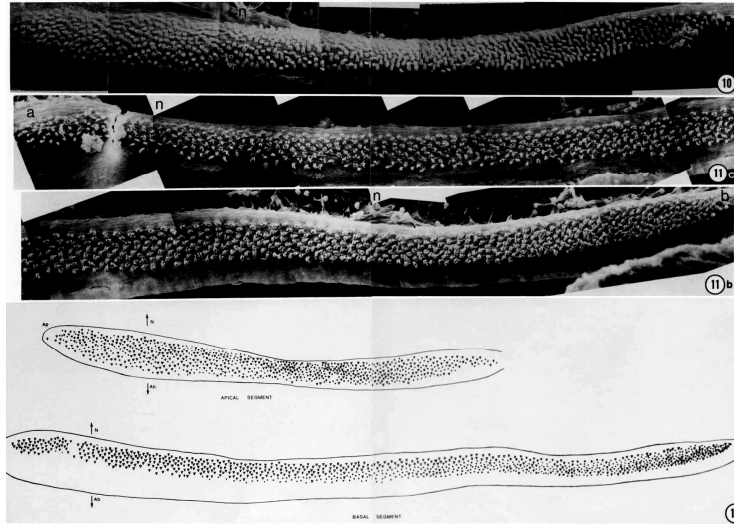
*Tiliqua rugosa*





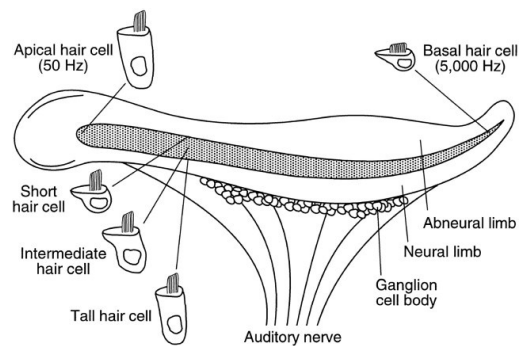
## The sensory epithelium in Lizards

Miller (1978) J Morphology



## The sensory epithelium in birds

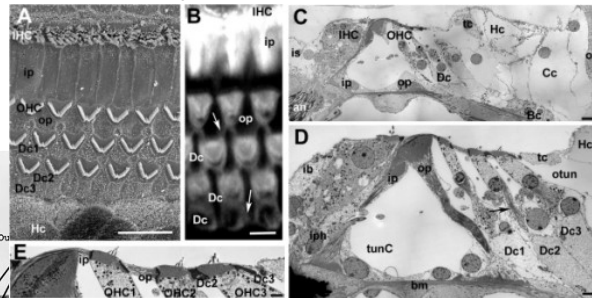
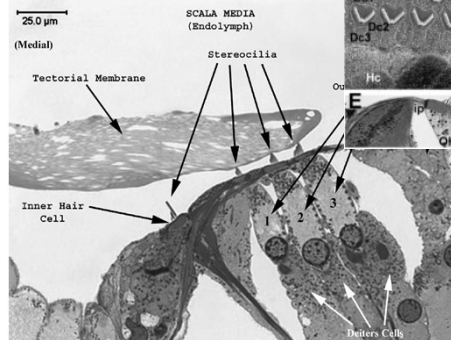
Basilar papilla: contains hair cells



Rosenblatt et al. 1997

## Auditory Hair cells: 2 types in mammals

### Mole Rat



### Mouse

Inner Hair Cell (IHC) : release **glutamate** onto auditory nerve fibers following **depolarisation**

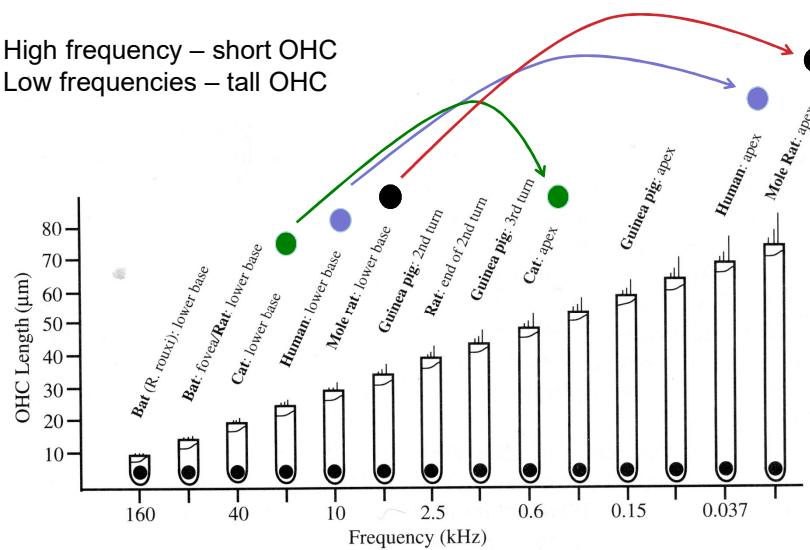
Outer Hair Cell (OHC): provide **mechanical amplification** at low to medium sound intensities (40-60dB gain).

Raphael & Altschuler (2003)

[https://openi.nlm.nih.gov/detailedresult.php?img=PMC3267727\\_pone.0030577.g001&req=4](https://openi.nlm.nih.gov/detailedresult.php?img=PMC3267727_pone.0030577.g001&req=4)

## Variations in mammalian hair cell anatomy

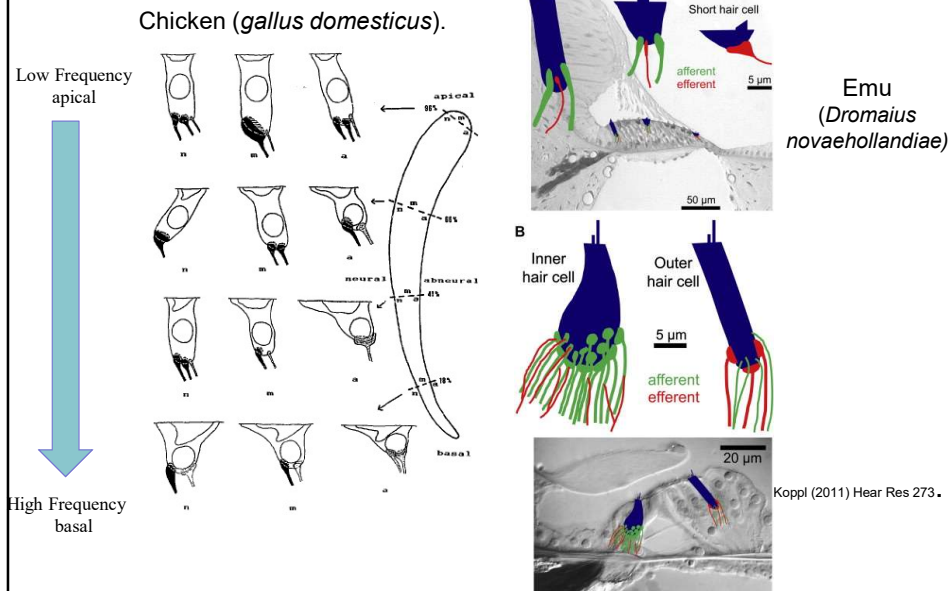
High frequency – short OHC  
Low frequencies – tall OHC



Fay & Popper (1994). Comparative Hearing: Mammals, p151



## Variations in hair cell anatomy: Avian Papilla.

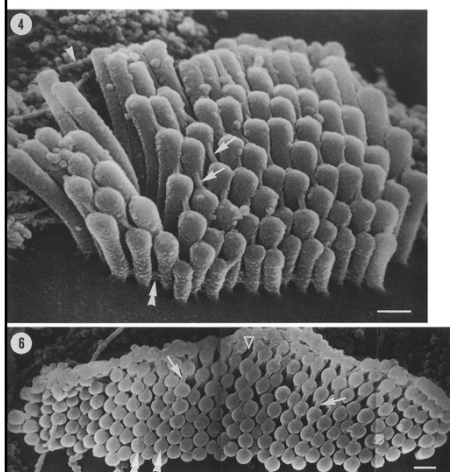


## What are the 'Hairs' ?

Stereocilia – cytoskeletal extensions from apical surface

**Birds/ Frogs/ Lizards**

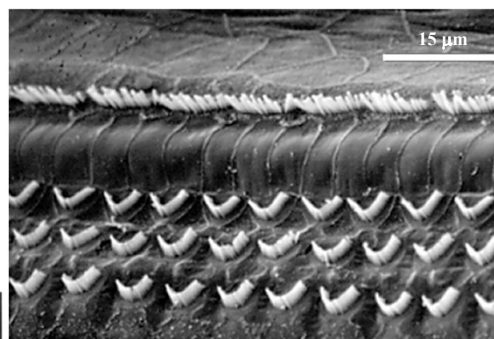
multiple **rows** per hair cell.



Raphael & Altschuler (2003) Brain Res Bull

**MAMMALS**

Usually **3 rows** per hair cell (small variation)

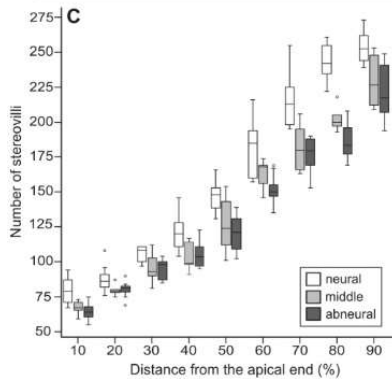
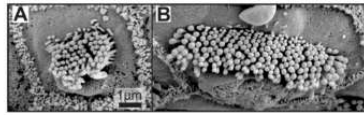


M Lenoir

## What are the 'Hairs' ?

### Birds (example Kiwi)

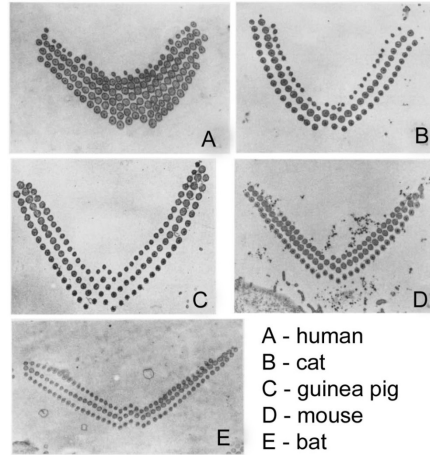
More stereocilia towards basal end



Corfield et al. 2011

### MAMMALS

Very little variation along basilar membrane and between species



Modified from Nadol (1988) Hear Res. Scale Unknown

## How many hair cells are there?

Counts of IHCs, OHCs, and SGNs.

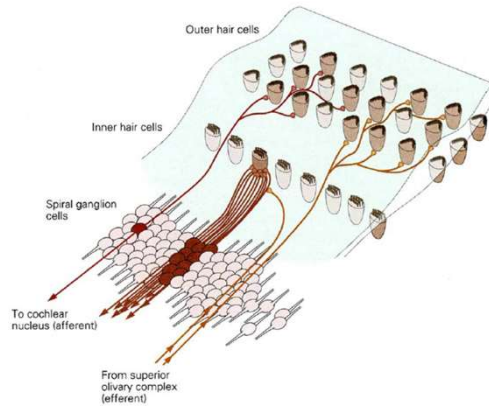
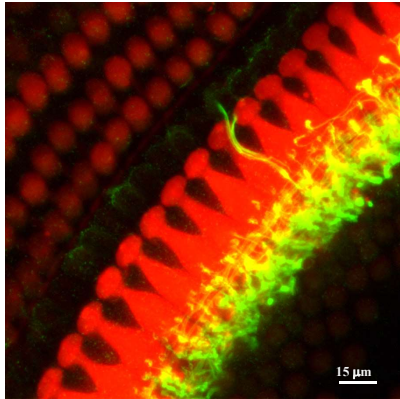
Species	IHCs	OHCs	SGNs	Reference
Echidna	2700	5050		Ladhams and Pickles, 1996
Platypus	1600	3350		Ladhams and Pickles, 1996
House Mouse	765	2500	12,350	Ehret, 1983
Rat	960	3470	15,800	Keithley and Feldman, 1979;
<i>Sprague-Dawley</i>			14,305	Berglund and Ryugo, 1991;
			19,229 ± 1049	Hall and Massengill, 1997
Guinea Pig		2400	24,011 ± 982	Gacek and Rasmussen, 1961;
			19,323 ± 1186	Firbas et al., 1970;
				Nadol, 1988
Cat	3000	9000	50,000	Retzius, 1884;
		9900	48,957 ± 1274	Held, 1926;
			50,558 ± 5285	Chen et al., 2010;
			51,574 ± 2933	Howe, 1934;
				Gacek and Rasmussen, 1961;
Squirrel Monkey			30,745 ± 2769	Alving and Cowan, 1971;
Rhesus Monkey			31,247 ± 2114	Gacek and Rasmussen, 1961;
Human	3700	14,600	30,000	Retzius, 1884;
				Rasmussen, 1940;
				Bredberg, 1968
Bottle-nose dolphin:	3451	13993	95 004	Wever et al., 1971
Turkey		12700	10946	
Japanese quail		8400	12331	Corfield et al. 2013
Emu		17500		Kopple et al. 1998
Gecko		2000	1900	Miller 1985

## What about innervation density?

Ratio Ganglion cells to Inner hair cells

MOUSE

IHC red, SGN dendrites green



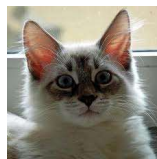
Kandel ER. Principles of Neural Science, Fourth Edition. New York: McGraw Hill; 2000:602

## What about innervation density?

Ratio Ganglion cells to Inner hair cells



Mouse: 13x



Cat: 10-26x



Horseshoe Bat : 8-24x



Turkey (birds): 1-1.5x



Little Brown bat: 70x



Monitor lizard: 1x



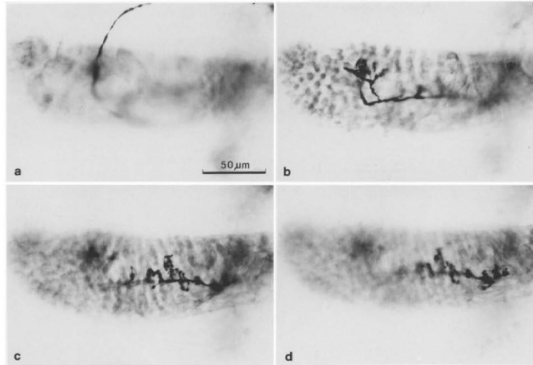
Bottle Nose Dolphin: 26x



Gecko gecko: 1x

## Innervation in lizard papilla?

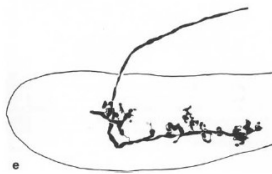
### Chemical Staining of single nerves



Different innervation pattern

1 afferent fibre contacts multiple hair cells.

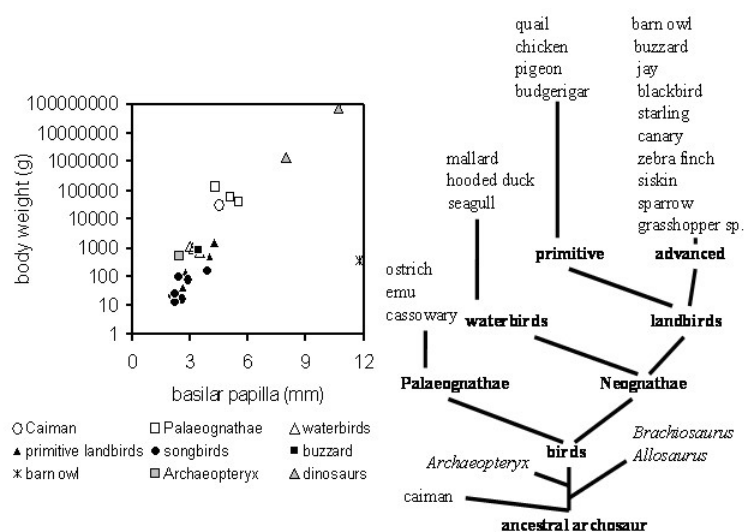
Divergent innervation.



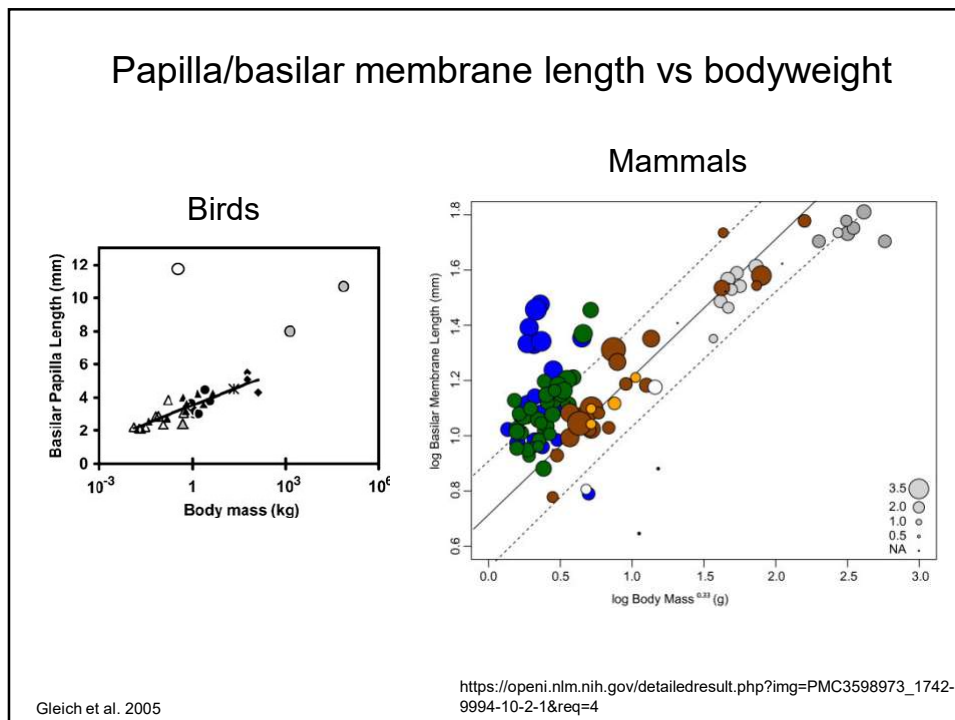
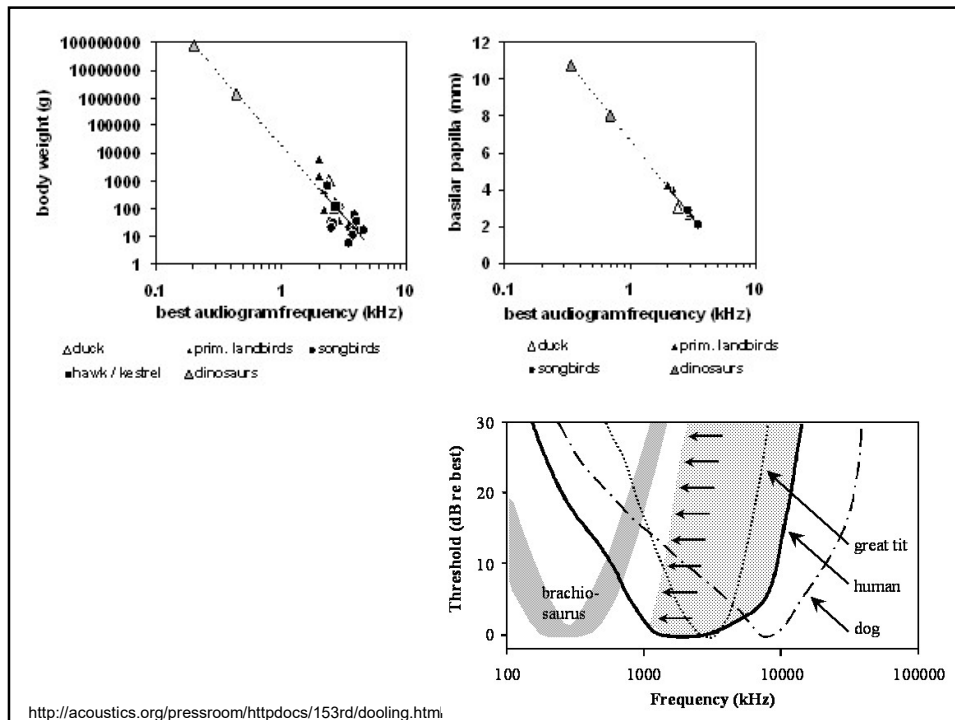
All stained neurones branched within the basilar papilla to innervate, typically, between 4 and 14 hair cells.

Koppl & Manley (1990) J Comp Physiol. (167)

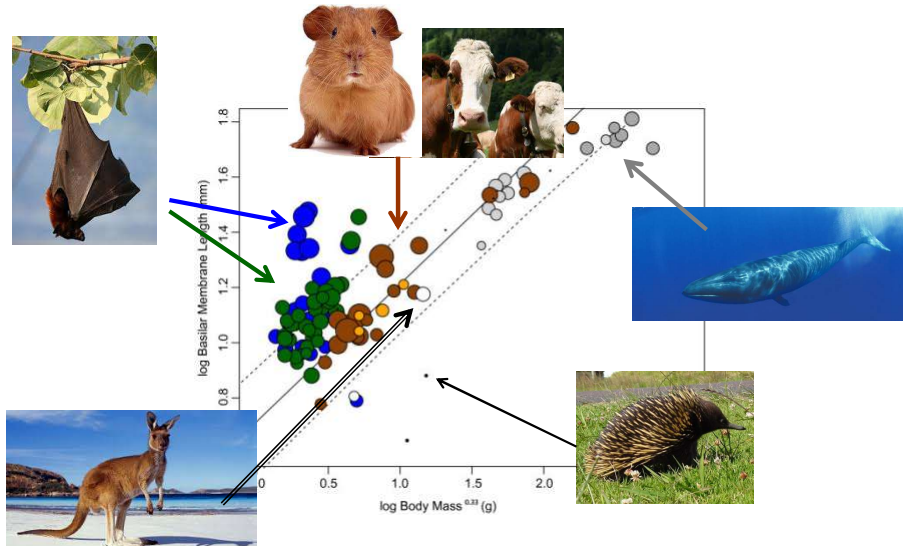
## Deriving new knowledge from comparative data



<http://acoustics.org/pressroom/httpdocs/153rd/dooling.html>



## Papilla/basilar membrane length vs bodyweight



[https://openi.nlm.nih.gov/detailedresult.php?img=PMC3598973\\_1742-9994-10-2-1&req=4](https://openi.nlm.nih.gov/detailedresult.php?img=PMC3598973_1742-9994-10-2-1&req=4)

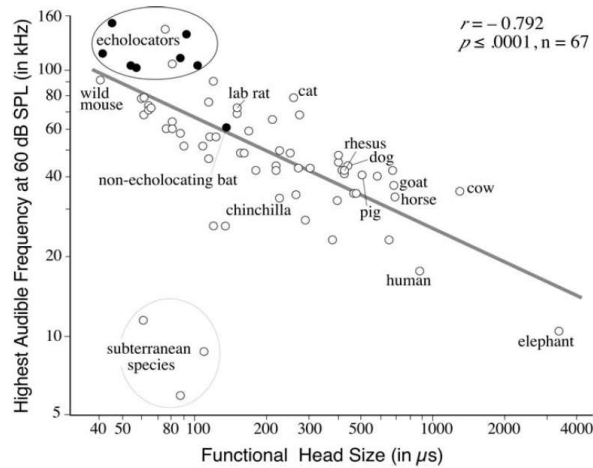
## Summary of anatomical variations/similarities

Parameter	Avian/ (Reptile)	Mammal/Primate
external ear	Hidden	Conspicuous
ossicles	typ. One (columella)	3 (incus, malleus, stapes)
cochlear shape	Curved/Linear	Coiled
hair cell types	Tall, Short	Inner/ Outer
stereocilia rows	Multiple	Usually 3
convergence ratio	complex	~15-20
basal end	High frequency	High frequency
apical end	Low frequency	Low Frequency
Tonotopic	Yes	Yes

The list goes on....and on.....



## And finally: size matters sometimes: Comparing hearing sensitivity for different head sizes in mammals



The smaller the head, the higher the 'audible' frequency

Small animals rely on high frequency sound cues to determine position.

Heffner (2008) in Dallos, Handbook of the Senses, p55

## Questions?

Corti

His Organ



## Further reading

Kandel et al. Principles of neural science. 4<sup>th</sup> Ed. 2000  
Purves et al. Neuroscience

Other texts as referenced on slides